

SOME OF THE ENGINEERING ASPECTS OF PASTEURIZATION*

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THE DESTRUCTION of bacteria by heat is a progressive reaction. For a given bacterial species, there is a definite death rate corresponding to each temperature within the pasteurizing range. This death rate increases rapidly with increasing temperature, and, at a sufficiently high temperature it becomes so rapid as to simulate an instantaneous killing. Probably the killing is never instantaneous whatever the temperature. At the temperature of pasteurization, there is a well defined death rate in which the time factor and the temperature factor are of equal significance.

The term "thermal death point," as used by bacteriologists, is indeed a misnomer. Bacteriologists long ago learned that in order to obtain consistent data on the thermal death point, or temperature at which death occurs, they must first agree upon a standard time of exposure to the heat. It is now well recognized that for any bacterial species, the so-called "thermal death point" is merely a single point, selected arbitrarily for descriptive purposes from a continuous series of similar points which taken together make up the "time-temperature death curve" of that species.

North has constructed certain of these time-temperature death curves, taking his data from various reported investigations upon some of the pathogens that may occur in milk. His curve for the tubercle bacillus is reproduced herewith (Curve II of chart). It shows that practically

complete killing of the organism in question may be obtained by exposure to 155° F. for about 1 minute, to 140° F. for 20 minutes, and to about 138° F. for 30 minutes. A similar curve, also by North, from his own studies, showing the effect of heat upon the creaming property of milk is likewise reproduced (Curve I of chart).

With this introductory discussion of the fundamental principle upon which pasteurization is based, a principle which unfortunately is not any too well known, we may proceed to the subject of the paper.

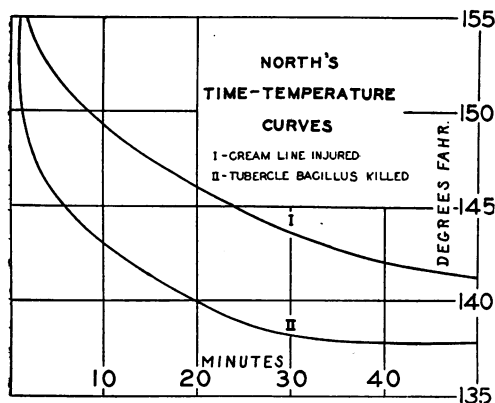
The title purposely draws attention to the fact that there is distinctly an engineering aspect to the problem of pasteurization. In fact, public health engineering may well claim pasteurization as one of its important branches, for the design and operation of pasteurizers are wholly matters of engineering. On the other hand, the facts as to the time-temperature death curve data upon which the entire process is based, must first be determined by competent bacteriologists. It is not the present purpose to discuss these data critically. As engineers we must assume the correctness of the basic data. Any modification the bacteriologists may later decide upon can readily be introduced into our procedure, without influencing in any material way the general principles upon which we may agree.

SUITABLE TIME AND TEMPERATURE

The two curves used to illustrate the basic data have been selected from a series

* Read before the Sanitary Engineering Section of the American Public Health Association at the Fifty-fourth Annual Meeting at St. Louis, October 22, 1925.

of curves published by North. The curve for the tubercle bacillus is the uppermost of four curves for pathogens commonly found in milk, while Curve I, showing the beginning of the effect of heat in reducing creaming, is the lowest of five curves relating to the physical and chemical properties of milk.



Any point on the chart above Curve II represents a time-temperature combination that will destroy the tubercle bacillus as well as those other pathogens, the curves of which lie below Curve II. Similarly, any point below Curve I represents a combination which will not injure the creaming properties, nor affect any of the other properties represented by North's other curves.

The primary object of pasteurization is the destruction of pathogenic bacteria, but commercially, and possibly from a nutritional standpoint, the physical and chemical properties of the milk must remain unimpaired. Thus, in pasteurization we are restricted to time-temperature combinations lying within the area between these two curves. Any such combination ought to yield a safe milk of satisfactory commercial quality.

To the engineer, however, other factors are at once apparent. We must have a reasonable limit of tolerance. At the extreme left, pasteurization at 155° F. or over for 1 minute or less is indicated as a possibility. This is the old flash method, discarded early in the history of pasteur-

ization because of its proven unreliability. An engineer can readily see that the difficulty of control within this region is altogether too great for a commercial process of this sort.

Between 10 and 30 minutes, the indicated zone offers ample tolerance for good control as to both time and temperature. It is significant that a time of 30 minutes has been quite generally accepted, despite obvious commercial advantages of shorter periods. This time was apparently established by adding a margin of safety to the time employed by Rosenau in his studies of the tubercle bacillus.

Twenty minutes happens to be a standard time adopted by bacteriologists for the determination of thermal death points. It has no particular significance. Had Rosenau and others adopted a 10-minute period in their studies of thermal death points, pasteurization would in all likelihood now be established upon a 15- or 20-minute basis.

At 30 minutes there is a temperature range of 5° in the restricted zone. At the midpoint of this range (141° F.), there is a time range of 30 minutes within the zone so that the permissible tolerance at 142° F. and 30 minutes is $\pm 2^\circ$ and ± 15 minutes. This is obviously disproportionate, although the indicated temperature tolerance is well within commercial possibility. On the other hand, with a 15-minute holding at 144° F., the permissible temperature range is $\pm 3^\circ$ and the time range ± 10 minutes, while at 10 minutes holding at 146° F., the tolerance becomes $\pm 3.5^\circ$ and ± 8 minutes. Making all due allowance for the necessary uncertainty in the basic data, it is clear that the possibilities of pasteurizing at holding periods of 10 to 15 minutes have not been properly appreciated, and that from an engineering point of view such procedures are entirely feasible and would represent considerable economy in equipment.

Whatever time period be adopted, it is clear that a corresponding temperature exists midway in the zone, which gives a

maximum range of permissible variation. At 30 minutes this temperature is about 141° F. To the writer's mind, this fact, assuming always the accuracy of the data, is a sufficient answer to the question now so much under discussion as to whether pasteurization should be performed at 142° F. or 145° F. The latter temperature is above the line at which cream volume is diminished and allows no proper tolerance in an upward direction.

TEMPERATURE CONTROL

It is a distinct advantage of the holding method of pasteurization over the flash method that in most of the holding systems employed there is considerable opportunity for mixing after heating. This mixing tends to average the temperature of the heated milk and makes permissible a certain degree of variation at the heater. Only in the continuous flow type of holding system is a close temperature regulation required. Automatic temperature controllers of several types are available, readily capable of controlling within 2° of the required temperature. The variations are of a periodic character, consisting of regular short time swings of half-minute intervals or thereabout. Such variations are partially absorbed in the metal pipe, and are evenly averaged out within a few minutes in the holding tank of the vat or pocket type.

As a general rule, more even temperatures are obtained with the larger volumes of heating water. In the heaters of the so-called barrel type in which a fixed and relatively small amount of water is held in the heater and itself heated by live steam, the control is more difficult and the resulting temperature record generally more ragged than in the tubular heaters having a circulating water supply externally heated.

For the more accurate control necessary in the continuous flow holders, the writer has found it desirable to employ a rather large auxiliary tank through which the heating water is circulated and in which a constant temperature is main-

tained by automatic control of the temperature of the returning water stream. The tank irons out all temperature waves due to the control mechanism.

Under proper conditions, such a water supply gives a smooth milk temperature chart. The essential conditions are a constant rate of flow of both milk and water, and not too great variation in the temperature of the cold milk. The greater the variation of the latter, the greater must be the water to milk ratio and the longer the heating system. With a water to milk ratio of 5 to 1 and a heating system capable of working with water only 10° above the required milk temperature, this system of heating will reduce a variation of 10° at the cold milk end to one of less than 1° at the heated end without further control. This type of temperature control, the control being entirely on the hot water, is one deserving of more serious consideration than it has hitherto received.

Temperature control must also be applied during the holding period. In addition to suitable insulation of the major apparatus, it is necessary most carefully to avoid exposed pipe, especially outlet connections from the bottom. In some tests of a well planned modern plant in which every precaution had been taken to secure results as nearly perfect as possible, a temporary thermometer was inserted in the outlet pipe which held about 1 gallon of milk, between the insulated portion of the holder and the valve. During the holding period the temperature in this pipe dropped 17°, while the drop in the holder itself was less than 1°.

Another fact of importance is that even an insulated tank will permit some cooling and this occurs at the walls. Convection currents flow down the walls and cool milk accumulates at the bottom. An average drop of 1° during holding may mean an actual drop of 5° at the bottom of the holder. This emphasizes the importance of thorough insulation, and the great advantage of a heated water jacket such as was used in some of the older equipment.

RATE AND TIME CONTROL

In the positive holding devices, the batch pasteurizers and the pocket type of continuous system, the holding time is, within the limits of the equipment, independent of the rate of milk flow, and is governed either manually or mechanically. In these cases, it is merely necessary to make sure that all the milk goes through the apparatus as intended. Valves such as are used on most pasteurizing equipment are seldom tight. The leakage is generally small but carelessness in this direction may lead to serious by-passing. A most urgent need is apparent for valves that are actually non-by-passing. This does not mean the manufacture of a tight valve, but calls for a new design which after being dented and worn in service may leak badly but in such a manner that it cannot by-pass.

In the continuous flow type of holder, time of holding is dependent first of all upon rate of flow and in such systems the rate has the same importance as the temperature. It should be controlled by an orifice or other hydraulic device, incapable of change by the operator, or manually in connection with an indicating and recording rate meter. In the latter case, the record should have the same status as the temperature record. It is indicative of the lack of appreciation of the fundamental importance of the time factor that ordinances require permanent temperature records of the operation, and yet leave the rate of pumping, and consequently the holding time in continuous systems, entirely at the discretion of the operator.

HOLDING TIME IN CONTINUOUS FLOW HOLDERS

In holders of the continuous flow type we define the ratio of the total capacity to the rate of flow per minute as the nominal holding time. Assuming steady stream-line flow at uniform velocity throughout the cross section, the nominal holding time would also be the effective holding time. Any interference with such

ideal flow makes for an uneven distribution of velocity and for the passage of a portion of the milk in less than the nominal time.

In continuous flow holders of the older type, vertical cylindrical tanks of large cross-sectional area compared with the height, there are numerous factors which interfere with uniform distribution of velocity. They may for convenience be classified as mechanical and thermal. The mechanical factors are velocity of entrance, uneven distribution of lines of flow at inlet and outlet and excessive velocity through the reduced openings of baffles. The thermal factors which lead to thermal convection currents are variation in the temperature of the incoming milk, and cooling at the walls through imperfect insulation.

All these factors are subject to fairly satisfactory control by good design. Velocity of entrance and uneven distribution are cared for by the use of a series of perforated baffles. Such baffles should have a relatively large area of opening, 15 per cent, so as to introduce little hydraulic resistance with its consequent disturbing velocity. To provide distribution they should be used in multiple, with openings mismatched or staggered. Distribution at the outlet may be secured by the usual type of baffle providing a considerable loss of head.

The thermal factors are provided for by use of a specially good temperature regulation, previously referred to, and by thorough insulation. The best results are obtained by housing the equipment in a small room in which a temperature a little over that of the milk is maintained by thermostatic control.

At best the hydraulic conditions in this type of holder represent a carefully balanced system of stability. The use of this type of equipment is justified only when every detail of satisfactory design has received attention, and then only with heating systems capable of control more accurate than usual. Furthermore, its operation must be most carefully attended.

The shortcomings of the continuous flow type of holder seem to have been entirely obviated in the case of one design now on the market. Instead of short upright cylinders, long horizontal pipes of 6 or 7 inches in diameter are employed. These are arranged in stacks connected at the ends with return bends. The whole is enclosed in a housing capable of being heated. The milk flows through a total length of some 300 feet.

Pure stream-line flow through such a device should result in a central velocity some 25 per cent greater than the mean. By increasing the length, however, until the velocity of flow exceeds the critical velocity, a turbulent flow is obtained, providing lateral mixing and off-setting this effect. The result is a remarkably even flow of the milk and uniform time of holding.

INDICATING AND RECORDING DEVICES

Thermometers found about a milk plant are usually of poor quality and inaccurate. Manufacturers should be induced to equip with reliable instruments. In particular, thermometers should have safety expansion bulbs above the scale to prevent strains and breakage during the preliminary warming up or final wash-out with hot water. Most thermometers have a scale poorly adapted to the purpose, with closely packed 2° lines and an unnecessary range. A special thermometer, covering a very limited range and with widely spaced single degree marks, is much needed and would undoubtedly be furnished if demanded.

The same criticism applies to the recording thermometers. In addition, their adjustable feature, usually open to the operator, makes their charts an extremely unreliable record. Fortunately there is on the market a short-range recording thermometer made especially for this purpose. The pen makes a narrow line over widely spaced single degree marks instead of the usual wide red mark covering about 2 whole degrees.

Thermometers of this sort should be

under lock and key, out of reach and out of sight of the operator. Their sole function is to give a true and permanent record of his work. The control of the operation should be based upon the regular equipment thermometer. On continuous flow systems a flow meter is as important as a thermometer and its readings should also be recorded.

TESTING

Testing the pasteurizing equipment for time and temperature is an engineering function. In positive holders this involves merely a checking of thermometers and of the mechanical control system. Equipment of this sort should, however, be tested for leakage and by-passing. This may be done with the use of dyes. Testing a continuous flow holder is a matter of more difficulty. It involves the addition of color during a continuous run, under conditions which preclude gravitational streaming of the dye solution by reason of its specific gravity. Samples of the effluent are collected for color reading. It is of little importance to determine the first appearance of colors, unless it be for a purely technical application of the law. The color solutions usually applied are powerful and as the writer uses them, capable of being read in less than 1 per cent of their original dilution at the top of the holder. Obviously, it is of practical importance to know how much milk is being held for any given period less than the nominal holding time.

The importance of the thermal effects has been sufficiently stressed to indicate the futility of any test made with cold water. The plant should be operated in the regular manner and the ideal test would be one made with milk. Its results should be expressed in the form of a table or plot showing the percentage of the total milk passing through in less than any specified time. This information is obtained by comparing the intensity of the color in a series of samples with that of the original colored water entering the holder.